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A major star formation region in the receding tip of the stellar Galactic bar

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ABSTRACT

We present an analysis of the optical spectroscopy of 58 stars in the Galactic plane at $\ell = 27^\circ$, where a prominent excess in the flux distribution and star counts have been observed in several spectral regions, in particular in the Two Micron Galactic Survey (TMGS) catalog. The sources were selected from the TMGS, to have a K magnitude brighter than +5 mag and be within 2 degrees of the Galactic plane. More than 60% of the spectra correspond to stars of luminosity class I, and a significant proportion of the remainder are very late giants which would also be fast evolving. This very high concentration of young sources points to the existence of a major star formation region in the Galactic plane, located just inside the assumed origin of the Scutum spiral arm. Such regions can form due to the concentrations of shocked gas where a galactic bar meets a spiral arm, as is observed at the ends of the bars of face-on external galaxies. Thus, the presence of a massive star formation region is very strong supporting evidence for the presence of a bar in our Galaxy.

Subject headings: stars: formation – Galaxy: stellar contents – Galaxy: structure.

1. Introduction

The barred nature of the Milky Way was first suggested by de Vaucouleurs (1964) in an attempt to explain the non-circular gas orbits. Since then, many types of observational supporting evidence have been accumulated. These comprise modern star-count data and surface photometry at different wavelengths, which suggest axial asymmetry of the internal bulge, stellar population studies in Baade's window, microlensing, and detailed analysis of the internal motions of the gas. Many review papers are cited by Blitz (1996).

In our analysis of the Two Micron Galactic Survey (TMGS) database (Garzón et al. 1993) we described evidence in favor of a central Galactic bar. In this paper, we present the results of a spectroscopic follow-up to the TMGS project, aimed at identifying the population content of the Galactic plane in selected regions. Here we concentrate on the $\ell = 27°$ area, where excesses in the flux distribution are very clearly observed in scans across the plane in the TMGS database and have been reported by previous authors at different wavelengths (Viallefond et al. 1980), to explore the hypothesis that we are looking at a star-forming region of particular strength.

2. TMGS star counts in the Galactic plane at $\ell = 27°$.

The TMGS catalog is composed of a series of slices at constant declination across the Galactic plane, each scan covering up to 30 degrees of latitude and a variable amount in longitude, ranging from 0.1 to 2.5 degrees (for details see Garzón et al. 1993). Hence the areas we are referring to here cover an area on the sky of roughly one degree in b, centered on the Galactic equator, by the amount in ℓ scanned by the TMGS at the given location.

Using TMGS counts Hammersley et al. (1994, hereafter HGMC) showed that at $\ell = 21°$ and $27°$there is a concentration of luminous stars within about a degree of the

plane, which, when the counts are plotted against latitude, form a spiked distribution on top of that expected for the disk and arms. Hence these latter two Galactic components cannot account for the observed stellar distribution.

HGMC argued that the spikes detected in the TMGS star counts and in the DIRBE surface photometry are both due to the interaction between the ends of the bar and the Galactic disk, which gives rise to star formation regions. Calbet et al. (1996) also pointed out that the infrared star-count distribution in the central regions can be explained in terms of a dust lane leading a Galactic bar at negative longitudes.

A clear excess in the star distribution is observed in the Galactic plane at $\ell = 27^\circ$ when compared with neighboring areas; namely, those at $\ell = 33^\circ$, $\ell = 21^\circ$ and $\ell = 16^\circ$ (HGMC). HGMC examined several possible scenarios to account for this excess, which is also noticeable in other types surveys (Viallefond et al. 1980; Hayakawa et al. 1981; Kawara et al. 1982; Kent et al. 1991). This spike is especially noticeable when the sample is limited to apparent magnitudes brighter than $m_K = 5$ mag. We concluded that the most likely explanation is the presence of a giant star formation region, which is most probably associated with the receding tip of the Galactic bar.

Mikami et al. (1982) studied this region using an objective-prism plate survey, and suggested that clustering of M supergiants must be the cause of the peak. We found their suggestion in agreement with our conclusion and, with this in mind, started an observational program aimed at spectroscopically classifying selected sources from the TMGS database, particularly those responsible for the spike at $\ell = 27^\circ$.

3. Observations and analysis

The observations were carried out at the Roque de los Muchachos Observatory on La Palma (Canary Islands, Spain) with the 2.5-m Isaac Newton Telescope using the Intermediate Dispersion Spectrograph (IDS), with the AgRed collimator and the R600IR grating (centered at 8500–8600 Å) and TEK3 chip CCD. The spectra cover the region from 7750 to 9400 Å and the spectral resolution attained with two selected instrumental configurations was 1.7 Å pix^{-1}.

We ran three campaigns in the summers of 1995 and 1996, taking some 70 spectra in total, 60 of which were identified as visible counterparts of TMGS sources. The targets were selected from the TMGS database in the Scutum region ($\ell = 27°$, $b = 0°$) using $m_K < 5$ mag as the selection criterion. After standard reduction, we examined the spectra for the IR Ca II triplet at 8498.02 Å, 8542.09 Å and 8662.14 Å, present in stars of spectral types later than F5. In earlier types, the Paschen hydrogen lines severely contaminate the spectral region of interest, making the Ca II triplet difficult to measure. For spectral types later than M4–5, TiO absorption bands mask the Ca II triplet almost completely. Jones et al. (1984) and Díaz et al. (1989) have calibrated the relationship between the equivalent width (EW) of the Ca II triplet and the luminosity class empirically for spectral types ranging from F5 to M3.

In Table 1 we give the coordinates of all the stars in our sample from the TMGS database. Investigators who may wish to use them should be aware that due to the intrinsic unaccuracies of the TMGS coordinates, which can be roughly estimated in 5″ to 10″, and the extreme crowdeness of the field there is often more than one visible candidate for the IR source.

EDITOR: PLACE TABLE 1 HERE.

These authors found some dependence of EW on both metallicity and temperature, but these were much weaker than the dependence on surface gravity. We have followed their results and adopted their criteria in assigning luminosity classes from the measured EWs. In practice, we classify a star as a supergiant (SG) by means of the EW of the two stronger triplet lines only in order to minimize the errors. The source is assumed to be a SG if the sum of the EWs of these two lines is > 9 Å, as in Díaz et al. (1989). The definition of the working continuum from which the EW is measured also followed that of Díaz et al. (1989). 38 stars in the sample were not contaminated with the TiO band, and we used the above method to get the EW. The remaining 22 stars belong to later spectral types, and the presence of TiO bands affects the triplet lines. For these objects we have evolved an empirical method which permits the measurement of EW in cases where the Ca II lines were not completely masked by the TiO band. This method uses the depth of the lines instead of the EW. First, we calibrated the relationship between line depth and the aggregated EW in the 38 stars where both quantities were measurable. We then used this relation to predict the EW from the measured line depth, where the Ca II lines are partially masked by the TiO band. Even with this technique, we had to reject two stars of the sample since the TiO band gave an unacceptable blend, so we finished with 58 stars that could be used.

The final results of the luminosity classification are shown in Fig. 1, in the form of a histogram of EW frequencies. Most noteworthy is the ratio of SGs (those with EW $> 9\mathring{A}$) to the total number, well in excess of 50%, with a high degree of confidence. The number of SGs is in fact 36 out of 58 (62%). This is strong evidence for the presence of a cluster of SGs, associated with a star-forming region. According to the model of Wainscoat et al. (1992), the disk and spiral arms can account for a maximum of only 20% of the SGs in this region. Furthermore, this model also predicts that there should be about 20 giants per square degree in the area, which is in approximate agreement with the number of giants found in this work. The remaining stars are either giants or dwarfs. For these a precise

segregation is not quite so straightforward since in these classes the effect of metallicity in the relationship between EW and $\log g$ is stronger. Following the above-mentioned criteria, however, we can classify as giants those with EWs between 6 and 9 Å, and as dwarfs those with EW < 6 Å. According to this criterion, there are no dwarfs in the sample, as expected from the K magnitude limit used for the selection of the sample.

3.1. Spectral classification

We have also performed a spectral classification by comparing our spectra with those of standard stars taken from the literature (Barbieri et al. 1981; Schulte-Ladbeck 1988; Bessel 1991; Torres-Dodgen & Weaver 1993). In Fig. 2 we show the frequency distribution of the spectral classes. As expected from objects selected on the basis of their K magnitudes, most of the stars are very red.

We also show in Fig. 3 a histogram of the frequency of different spectral types for the SGs only. For the SGs K is the most frequent spectral type, although our method of predicting the EWs where the TiO band affects the Ca II lines tends to underestimate the EWs, thereby reducing the apparent fraction of SGs in the coolest (M) class.

4. Star formation region

According to Bica et al. (1990a, 1990b) the red supergiant phase in a cluster is reached at an age of ~ 10 Myr. This implies that we are looking at a region in which the star formation is of recent origin, and that the star formation has taken place in the area observed, since such a short time does not permit the stars to move very far from their birthplace. This means that we can estimate the distance to the star forming region from the TMGS apparent K magnitudes by using the absolute K magnitudes associated with

known spectral types and luminosity classes, which can be found in the literature (Johnson 1966; Lee 1970; Blaauw 1973; Ishida & Mikami 1978). Since these sources are buried deep in the Galactic plane (we estimate their visible magnitudes to be about 16 mag), the probability of finding counterparts in existing visible catalogs is virtually nil. We adopted the extinction model of Wainscoat et al. (1992).

The result, in terms of the distance distribution, is plotted in Fig. 4. This histogram shows two maxima, one at distances of between 2 and 3 kpc and the other peaking at around 6 kpc. The first peak can be attributed to young-disk supergiants along the line of sight. The second peak is more spread out, but this dispersion can be explained by the uncertainty in the distance determination (due to errors in both the TMGS photometry and the assumed absolute magnitudes), which increases with distance. This peak, then, is formed by stars at distances ranging from 5 to 8 kpc; 24 of the 36 SGs belong to this peak. This SG concentration cannot be explained in terms of disk and/or bulge population, since these are mainly formed by old stars, so it must be attributable to some other component.

Since this region is not prominent among the main H II radio sources in the Galactic plane (Georgelin & Georgelin 1976), it must be embedded in another feature, such as an arm, a ring or a bar. Several authors have used Galactic models which include ring components to explain the excess flux observed in these regions (Mikami et al. 1982; Ruelas-Mayorga 1991; Kent et al. 1991). However, HGMC argued that if a ring is to be the feature where this star-forming region is located, then the ring has to be highly non-circular and discontinuous, as the observed peaks in star counts are not symmetrically distributed in longitude with respect to the Galactic center.

The arms can be quickly discarded since their tangential cuts are not in the direction of this region. From a number of morphological and modeling arguments discussed in HGMC, we have reason to think that neither a spiral arm nor a ring can be the morphological

structure within which this region is situated. A ring can also be excluded with fair probability since it should be prominent in other TMGS regions closer to the center than ℓ=27°, which is not the case. This argument is of course not as powerful as that for excluding arm sources.

5. Conclusion

We have found a star formation region located a $\ell = 27°$ in the Galactic plane. This region extends, presumably, to at least $\ell = 21°$, as can be deduced from the star distribution in the TMGS. The most likely explanation is that the Milky Way is a barred galaxy, and that this star-forming region is the result of the interaction between the suggested bar and the Scutum spiral arm. HGMC inferred a maximum position angle for the bar of 75°by considering that the ends of the bar are located at $\ell = 27°$ and $-22°$. This geometry is compatible with the range of distances that we have obtained for the star-forming region.

The Isaac Newton Telescope is operated on the island of La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofísica de Canarias.

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Fig. 1.— Star counts *vs.* equivalent widths.

Fig. 2.— Spectral types in the observed sample.

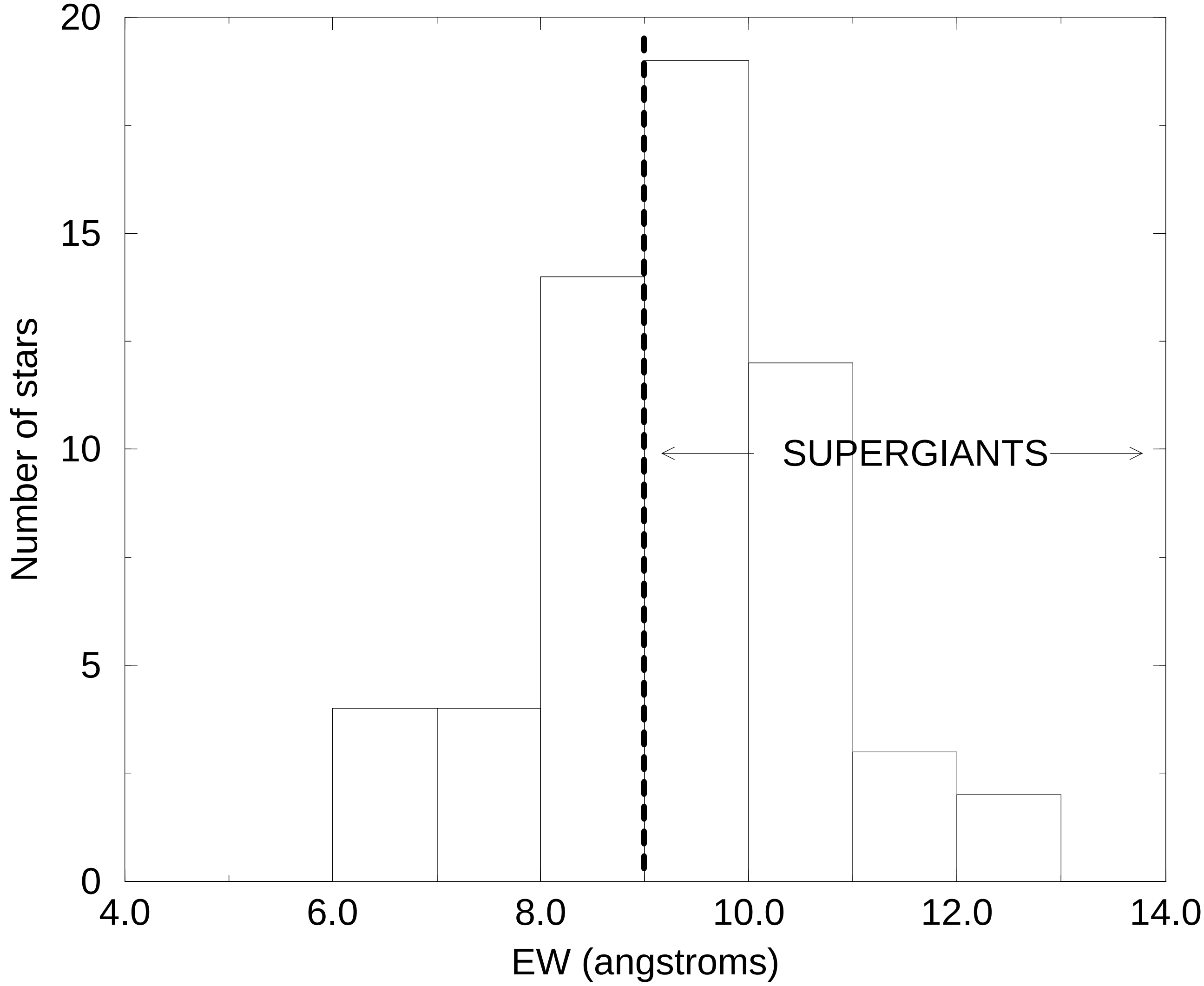
Fig. 3.— Spectral types for the supergiants.

Fig. 4.— Distances.

Table 1. Coordinates of the TMGS sample.

Right ascension ($^{h\ m\ s}$) and Declination ($^{\circ\prime\prime\prime}$) (J2000.0)											
18 30 28.2	–5 12 34	S	18 35 36.0	–5 03 57		18 39 36.1	–5 16 48	S	18 43 25.9	–5 11 33	
18 30 52.9	–5 08 24		18 35 45.4	–5 20 15	S	18 39 49.8	–5 18 20		18 44 26.2	–5 14 49	S
18 31 57.2	–5 13 05	S	18 36 23.0	–5 07 04	S	18 39 58.2	–5 16 45	S	18 44 47.1	–5 14 51	S
18 32 04.3	–5 13 31	S	18 37 17.7	–5 16 12	S	18 40 01.0	–5 14 11		18 45 08.7	–5 12 34	S
18 32 17.6	–5 12 34	S	18 37 26.0	–5 05 08	S	18 40 01.7	–5 13 01		18 45 12.4	–5 16 50	
18 32 21.3	–5 14 51	S	18 37 45.9	–5 20 29	S	18 40 49.0	–5 05 23		18 45 34.2	–5 12 33	
18 32 29.0	–5 16 50	S	18 37 53.2	–5 04 32		18 40 49.1	–5 05 28		18 45 40.0	–5 07 00	S
18 32 33.2	–5 16 49		18 37 54.5	–5 14 48	S	18 41 21.2	–5 16 17	S	18 45 41.9	–5 14 48	
18 32 34.4	–5 14 49	S	18 38 05.7	–5 19 37	S	18 41 36.0	–5 13 24	S	18 45 43.9	–5 15 21	S
18 33 05.3	–5 17 40	S	18 38 23.8	–5 15 42	S	18 42 03.6	–5 04 54		18 45 47.1	–5 17 45	S
18 33 06.9	–5 09 47		18 38 39.2	–5 12 22	S	18 42 14.3	–5 11 30	S	18 45 53.6	–5 21 05	
18 34 35.2	–5 11 56	S	18 38 50.4	–5 12 31	S	18 42 17.8	–5 13 06		18 51 37.1	–5 20 11	
18 34 37.3	–5 15 05		18 39 05.4	–5 12 28	S	18 42 35.1	–5 16 50		18 54 39.8	–5 11 43	S
18 35 12.5	–5 17 44		18 39 28.2	–5 14 47	S	18 42 50.2	–5 18 23	S			
18 35 35.3	–5 04 01	S	18 39 32.9	–5 15 19		18 43 15.5	–5 17 48	S			

Note. — S: source has been classified as a supergiant.


SUPERGIANTS
Number of stars
EW (angstroms)
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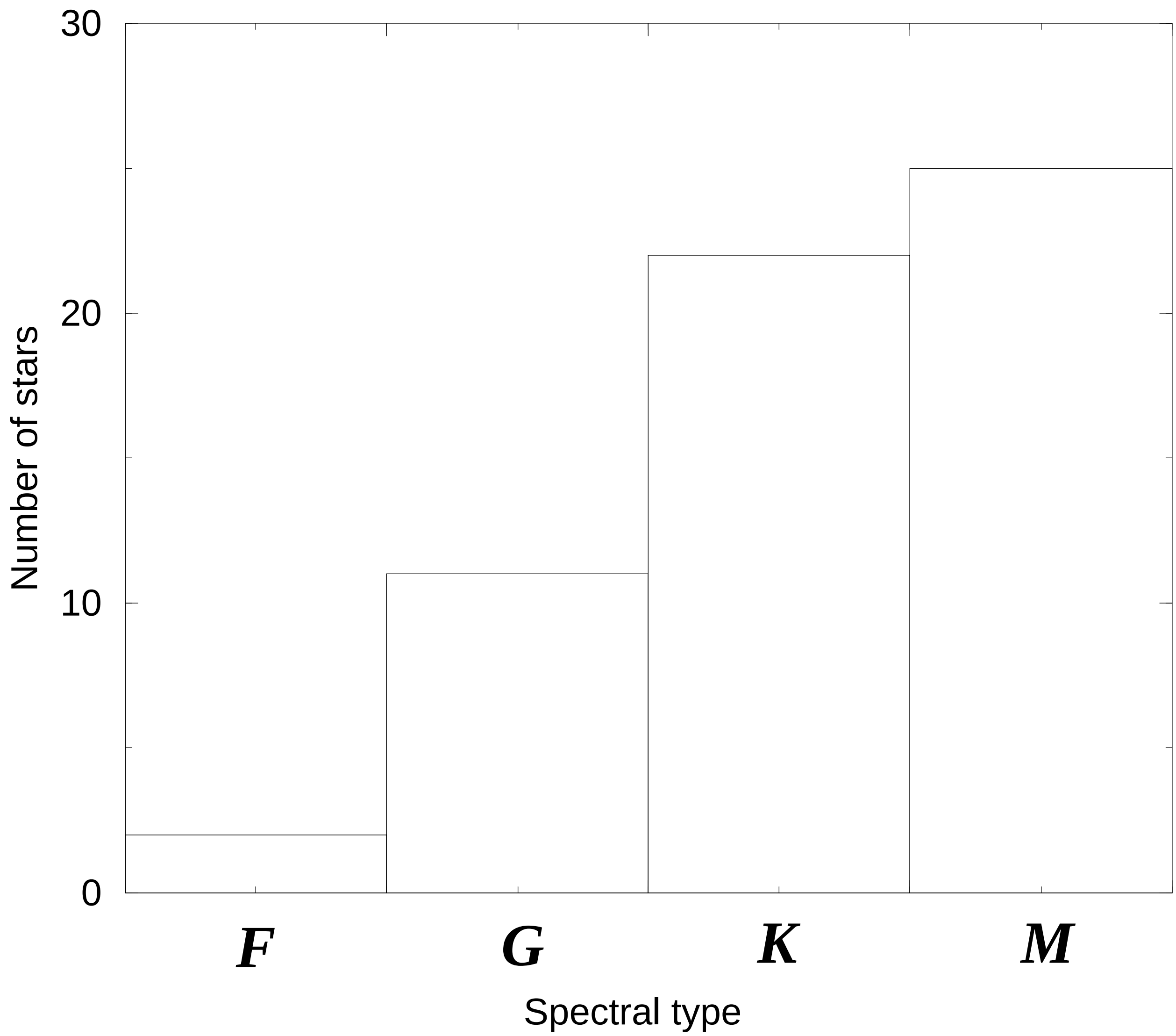
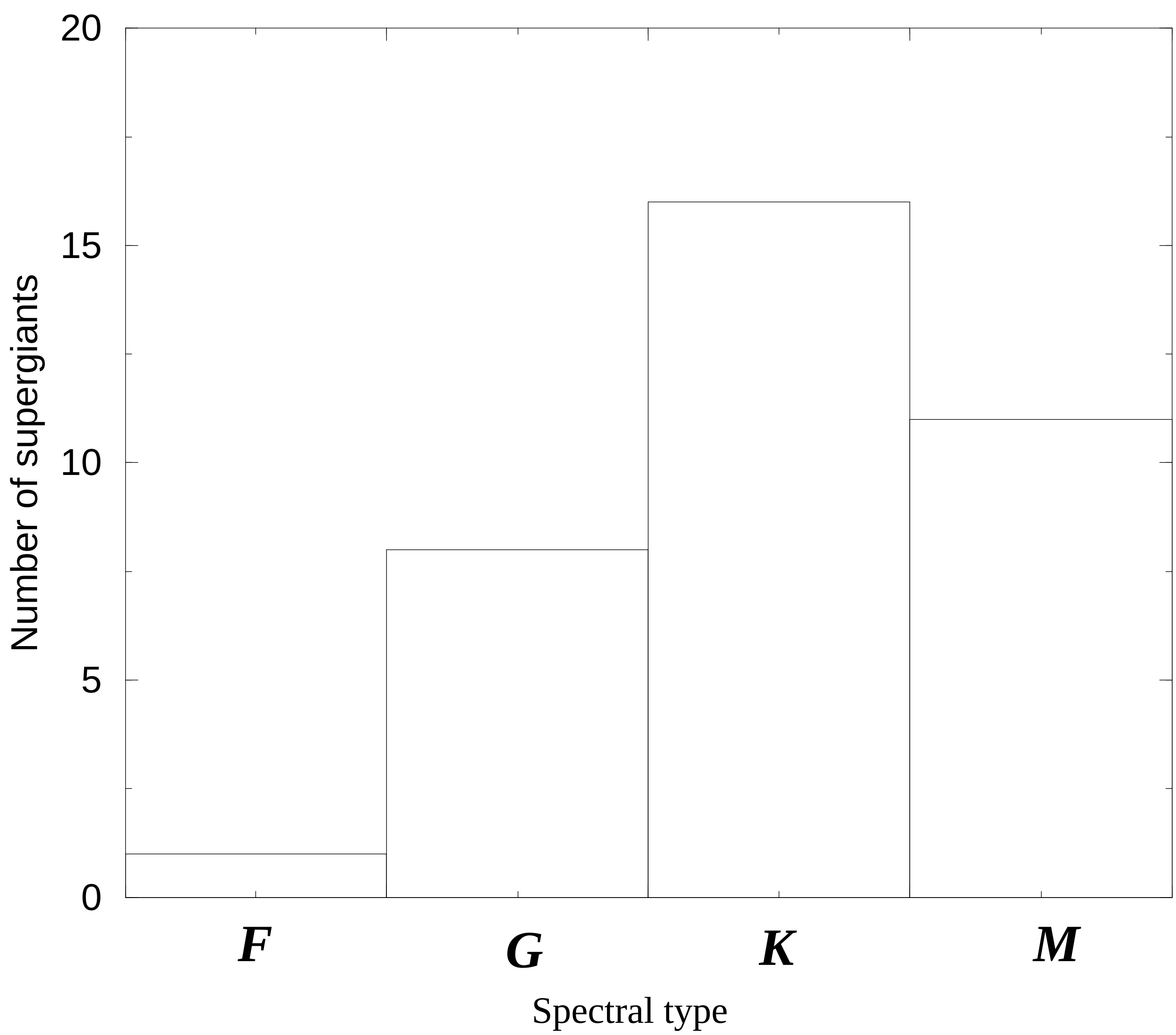
5
10
15
20
4.0
6.0
8.0
10.0
12.0
14.0



30
20
10
0
Number of stars
F
G
K
M
Spectral type


Number of supergiants
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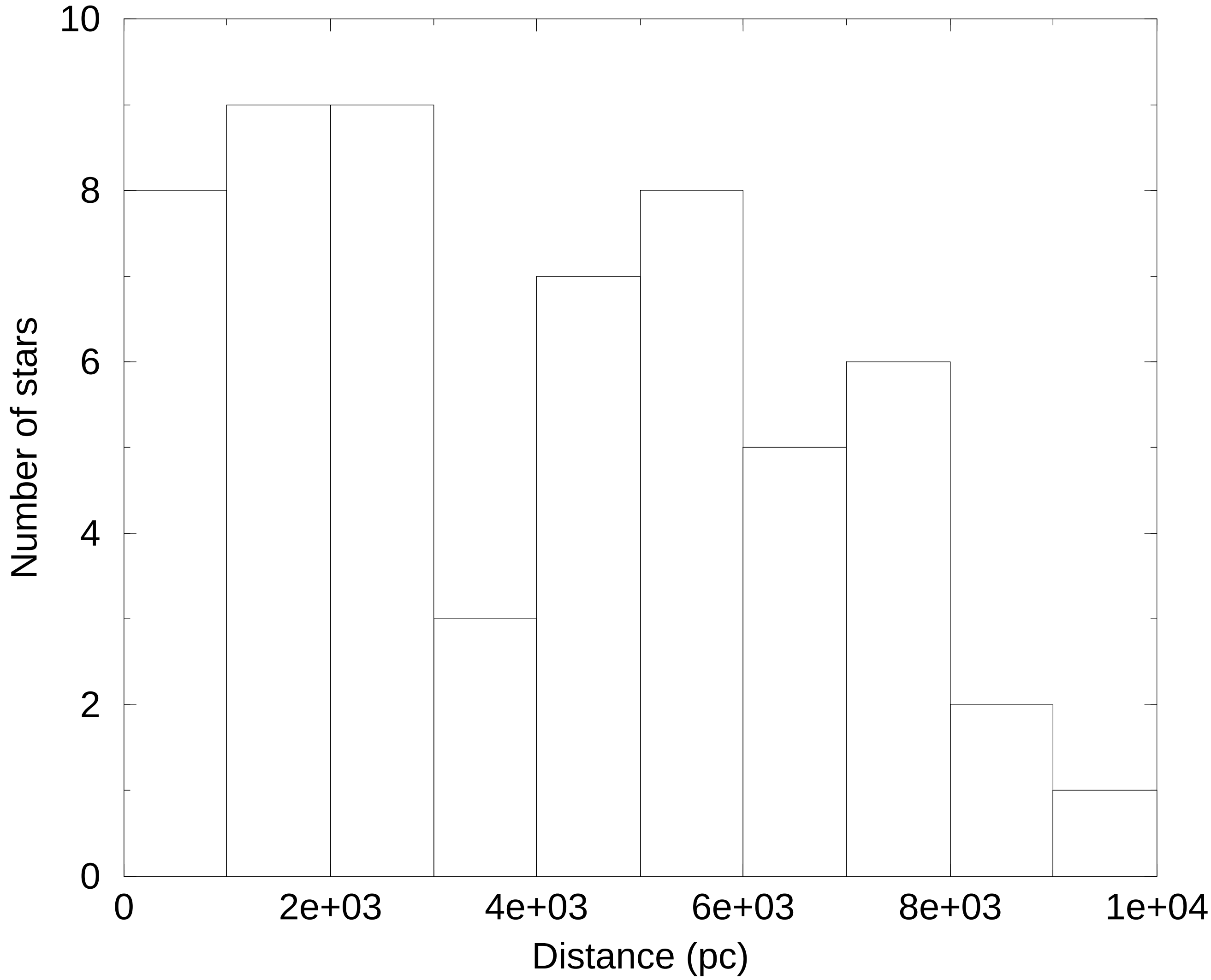
5
10
15
20
F
G
K
M
Spectral type



10
8
6
4
2
0
Number of stars
0
2e+03
4e+03
6e+03
8e+03
1e+04
Distance (pc)